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Defense Intelligence Agency
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Identification of Radiation Sources in a Peacetime Environment

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Prepared by:

Epidemiology and Environmental Health Division
Armed Forces Medical Intelligence Center
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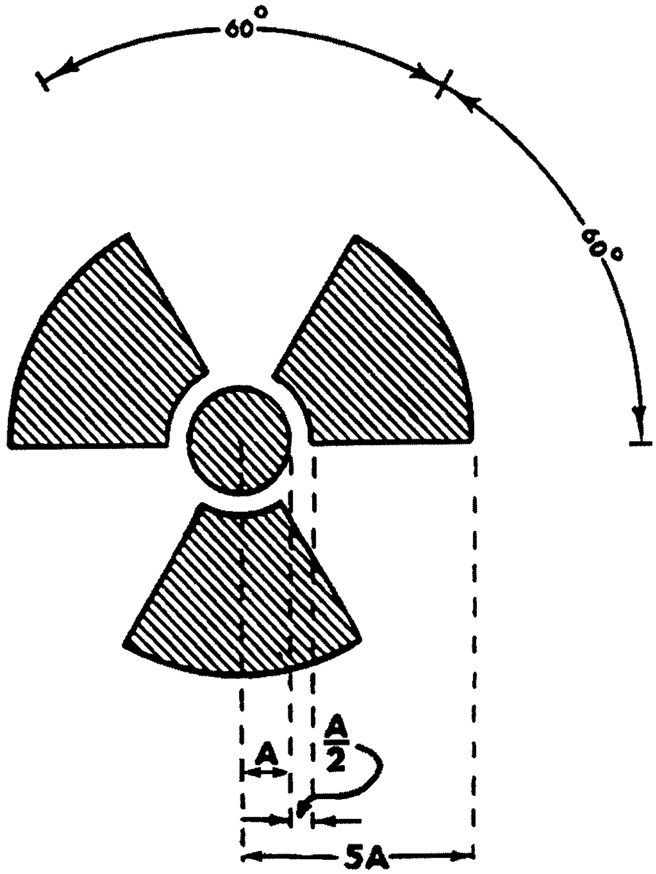

Standard Radiation Symbol. Used on containers, equipment, and posted on doors or walls. (Courtesy of Federal Regulations, Title 10, Part 20, 1901).

Preface

The purpose of this handbook is to aid individuals who may encounter radioactive materials in unfamiliar forms, in facilities damaged by natural catastrophe, or as a result of war in foreign countries. Individuals may encounter radioactive materials used in situations or in a manner that is not only unfamiliar but also potentially hazardous. Individuals may be required to perform peace-keeping or humanitarian operations in areas where radiation warning placards, signs, and instructions may be posted in a language other than English.

For these reasons, this handbook provides an overview of typical uses of commonly encountered radioactive materials, their identification, and a brief description of general radiation safety measures. The intended purpose of this handbook is to provide background information as an aid in the identification of sources of ionizing radiation and some basic radiation protection guidance. This handbook may be used in conjunction with specific procedures provided by senior echelon directives.

This is the second edition of the handbook entitled "Identification of Radiation Sources in a Peacetime Environment." The handbook has been expanded to include graphics of commonly encountered equipment seen in a nuclear medicine department or nuclear pharmacy, radiation therapy sources, industrial food irradiation facilities, and small instrument check sources encountered in any facility using radiation detection equipment to validate equipment operation.

Request any amplification of subject matter, constructive criticism, comments, or suggested changes be forwarded to the Director, Armed Forces Medical Intelligence Center, 1607 Porter Street, Fort Detrick, MD 21702-5004.

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General Radiation Protection Guidelines and Terminology

Radiation emissions through radioactive decay is a natural process in which an unstable material achieves stability through the release of energy from within the atom. Unstable atoms release energy in several forms as they achieve nuclear stability. This continuous release of energy over time is radioactive decay, and the time required for one-half of the material to undergo this decay process is a material's "half-life." The half-life is unique to that radionuclide and cannot be slowed or accelerated.

The release of energy from an atom can take the form of a particulate (alpha, beta, or neutron) or the form of rays of electromagnetic energy (x- or gamma photons or rays). Whatever physical form the energy takes, some general guidelines regarding radiation protection are provided below.

Minimize time near a radiation source to reduce total exposure. Since an individual's total absorbed dose is defined as the dose rate times the duration of exposure, reducing exposure time will reduce the absorbed dose correspondingly. Remember, radiation detection equipment displays exposure rate per unit time, such as milliroentgen or milligray (mR or mGy) per hour. Exposure of less than an 1 hour will reduce the absorbed dose proportionately.

Maximize distance from a source to reduce exposure. Exposure and the absorbed dose from a source is related to the distance you are from the source. In other words, the greater the distance from the source, the lower the absorbed dose received from that source. This is known as the inverse square law. For example: doubling the distance from a source will reduce an exposure by a factor of four. Likewise, halving the distance from a source will increase the exposure by a factor of four.

Maximize shielding or material between you and the source of radiation. Radiation travels in a straight line and is capable of penetrating solid objects to great depths. By passing through objects, radiation "loses" some of its energy by interacting with the atoms within the object. In general, materials that have more atoms (or greater atomic density) will offer greater protection from photons. Denser materials are more effective as shielding materials than low-density materials. Neutrons, on the other hand, lose energy by interacting with hydrogenous materials (those containing a lot of hydrogen), such as water, plastic, or oil. Always maximize shielding between you and the source of radiation.

Radiation vs. Contamination

The two terms, radiation and contamination, are often confused. Radiation is the energy emission from the atom and may be released in the form of electromagnetic energy or particles. Radioactive materials emit radiation uniformly in all directions but may be scattered non-uniformly depending on the surrounding material. Contamination is the "physical relocation" or transfer of radioactive material from one place to another, such as to clothing, skin, or shoes, which may continue the spread of contamination.

Irradiation

Irradiation occurs when an object is exposed to a source of radiation. Although an object is exposed to radiation (irradiated), it does not become radioactive as a result. Unless radioactive contamination has been physically spread to the object, an exposure to a radioactive source will not cause the object to become "radioactive." For example, food irradiation will not cause the product to become radioactive as a result.

Machine Sources of Ionizing Radiation

Background Discussion

X-rays are produced when an accelerated beam of electrons strikes a high density target material, such as tungsten. During the process, most of the electron's energy is converted to heat (approximately 99 percent heat with only 1 percent useful x-ray production) that is deposited in the tungsten target. X-rays are emitted from the x-ray tube head through a collimated (focused) window, which focuses the beam. X-rays are ONLY produced when the x-ray tube is energized (powered up). Components of an x-ray machine are not radioactive, and the machine is not a source of ionizing radiation when the power is disconnected.

Diagnostic X-Ray Machines

For medical x-ray units, the tungsten target is disk shaped and must be in constant rotation to prevent it from melting because of the heat. The rotating disk within the x-ray tube head produces the distinctive "noise" heard during an x-ray generation. If the noise is absent, the equipment probably is not generating x-rays. In certain cases, such as dental x-ray machines or older fixed anode x-ray machines, there is no rotating tungsten disk target. As such, the distinctive rotation noise from the tube head will be absent even though the device is emitting x-rays. Both devices mentioned must still be energized for the production of x-rays to occur.

Medical (or diagnostic) x-ray machine sources may be located in clinics, hospitals, or mobile units. Typically, due to the weight and complexity of the x-ray machine and support equipment (large power supply, film developing with dark room, control console), these devices are usually located on the ground floor or basement level.

Portable X-Ray Machines

A diagnostic x-ray machine may also be portable and can be located anywhere within a clinic or hospital. A portable x-ray machine has an x-ray tube and control console mounted on a self-propelled chassis. The x-

ray tube is mounted on a boom attached to the unit and can be positioned over a bedridden patient. Portable x-ray machines are usually equipped with large storage batteries and are capable of producing x-rays when not plugged directly into a power supply. The machine will not produce x-rays when turned off or when the batteries are exhausted.

Industrial X-Ray Machines

Industrial radiography uses specialized x-ray machines for the examination of aircraft structural integrity and piping welds. Unlike medical x-ray machines, which have rotating tungsten anodes, industrial x-ray machines have large fixed anodes that do not rotate. Since there is no audible indication that x-rays are being produced, manufacturers often will equip units with a rotating beacon to alert those in proximity of the machine. Industrial x-ray machines may be located at aircraft construction and maintenance facilities, major airports, ship building facilities, and industrial centers where welding operations are conducted.

Linear Accelerators (LINACs)

Linear accelerators (LINACs) are used in radiation therapy as a source of high energy ionizing radiation used in the treatment of cancer. Electrons are accelerated to a velocity approaching light speed (90%) and bombard a fixed target producing very high energy x-rays. A LINAC is similar in size and shape to a teletherapy unit and will be located in a maze and vault structure in the basement or ground floor of a hospital or cancer treatment facility. Because of the complexity of design and operation, LINACs will be used in facilities with similar advanced technologies. The machine will not produce x-rays unless energized.

Radioactive Sources Commonly Used in Biomedical Research

Background Discussion
Facilities involved in biomedical research will use some or all of the following radionuclides: carbon-14 (C-14), iodine-125 (I-125), phosphorus-32 (P-32), tritium (H-3), and sulfur-35 (S-35). These radionuclides are commonly used in laboratories for the analysis of biological functions. Because the activity (quantity) of these radioactive materials is typically very small, biomedical radionuclides may be stored on the shelf without apparent shielding. The only indication that a laboratory may be involved in biomedical research using radionuclides may be posted signs with the radiation warning symbol (front cover) or individual bottles containing radioactive agents marked with the radiation warning symbol.

Laboratories that use radioactive materials may be located in hospitals or clinics, universities, and biochemical and biomedical research and development centers.

Common Radionuclides Used in Research*

Name	Half-Life	Emission	Energy (MeV)
Carbon-14 (C-14)	5,745 years	Beta	0.045 Average
Iodine-125 (I-125)	60.2 days	Gamma	0.035
Phosphorous-32 (P-32)	14.3 days	Beta	0.690 Average
Tritium (H-3)	12.6 years	Beta	0.0057 Average
Sulfur-35 (S-35)	87.9 days	Beta	0.049 Average

** List does not include all research radionuclides.*

Detection
Survey instrumentation required for monitoring radionuclides used in research must be sufficiently sensitive to detect very low energy and low activity. Detection of radionuclides at the threshold of detection energy requires either a thin window (Mylar) ion chamber or a low energy scintillation detector. Liquid scintillation is the only method of detecting and measuring low energy H-3, and commonly, C-14 beta emissions. Analy-

sis can be performed only in a laboratory equipped with a liquid scintillation counter.

Protection

No specific personnel protection equipment is required if entering a facility where radionuclides listed above are used. However, if individuals will be handling any object located within the facility, disposable gloves and laboratory coat or apron should be worn. All eating, drinking, smoking, or application of cosmetics is prohibited in a facility that contains unsealed radioactive materials, because ingestion of these particular types of radionuclides is a major concern.

Whenever unsealed radionuclides are used within a biomedical or biochemical laboratory, all equipment within the facility must be considered contaminated unless determined otherwise. In other words, all test tubes, pipettes, contents of waste or trash containers, laboratory countertops and surfaces, refrigerators, etc., must be assumed to be contaminated unless otherwise verified.

Hazard Warning and Decontamination Procedures

No specific health warning is issued when entering a facility that uses the radionuclides listed above. Beta emitting radionuclides used in biomedical research emit low energy particles which are not an external hazard because of their inability to penetrate skin or clothing, but are an internal hazard. Personnel or facility monitoring with hand-held radiation survey equipment is extremely difficult, if not impossible, to perform.

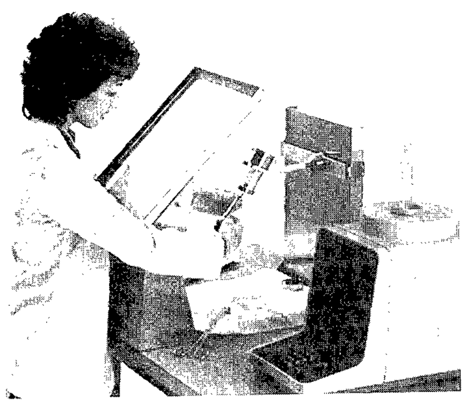
Decontamination procedures of externally contaminated skin must include a thorough soapy shower, rinse, and repeated cleansing. Decontamination must never be conducted to the point which the skin becomes abraded or redness occurs. When finally rinsed, skin should be allowed to air dry or lightly patted with an absorbent material and not rubbed. Monitoring decontaminated surfaces is difficult when dealing with low energy, low activity radionuclides. Contaminated surfaces should be considered sufficiently decontaminated after a thorough cleansing, rinse, and drying.

Phosphorus-32 (P-32) possesses sufficient energy to produce beta burns if exposed skin is not decontaminated promptly. In addition, many facilities use I-125 in relatively large amounts (2 to 10 millicuries or mCi) in the form of sodium iodine. This amount of iodine in the chemical form of sodium iodine can present a significant hazard if it is accidentally ingested or inhaled, with the radionuclide concentrating in the thyroid gland.

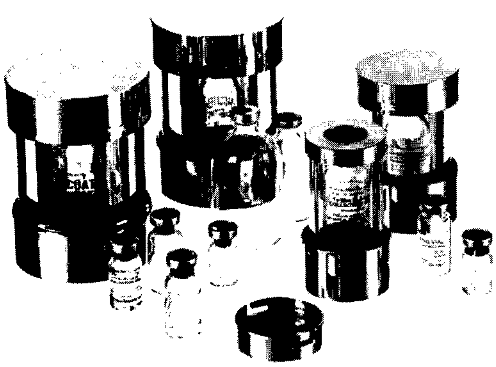
Disposal

Facilities that use radionuclides in biomedical or biochemical research will often maintain radioactive waste onsite in barrels or drums. Because of the number of barrels required for decay-in-storage, barrels may or may not be located on the grounds of the facility. If storage is located on-site at the facility, the barrels will usually be stored in the basement, in underground tanks, or on "barrel farms" on or adjacent to the facility. If a large number of barrels are located, do not handle, open, or tamper with the containers until they are examined by qualified personnel.

Radioactive waste for radionuclides with half-lives of 120 days or less may be stored onsite until it loses activity through natural decay (decay-in-storage). Waste must be stored for at least 10 half-lives before disposal (the activity will have diminished to "essentially" zero), and can be disposed of via sanitary sewer or as trash. Radionuclides such as H-3 or C-14 cannot be stored onsite for decay-in-storage because of their extremely long half-lives, and must be properly buried in authorized disposal facilities in sealed containers. If the original activity is minute (nanocurie [1×10^{-9} Ci] or picocurie [1×10^{-12} Ci] level), the radionuclide can be disposed of directly into the sewer system, providing there is adequate dilution with running water. "Adequate dilution" usually means that water runs continuously in the laboratory sink (or at the site at which the radionuclide enters the waste stream), and there is sufficient distance traveled to allow for mixing and dilution. Typically, the distance from the laboratory to the street is sufficient to allow for dilution if a large quantity of water is used. However, prolonged use of this method may trap and concentrate radionuclides in the piping system and present a hazard when breached.



Typical Radiation Protection Equipment. Found in a biomedical research facility or a nuclear medicine department. (Courtesy of Cone Instruments)



Shielded Vials. Commonly found in facilities for the safe handling of radioactive liquids. (Courtesy of Cone Instruments)

Radioactive Nuclides Commonly Used in Nuclear Medicine

Background Discussion

Radionuclides are commonly used in the diagnosis of disease in nuclear medicine. Procedures typically use technetium-99m (Tc-99m) as the radionuclide of choice for imaging by gamma scintillation camera. Tc-99m is extracted from a Mo-99/Tc-99m generator system and bound to "tracer" molecules in the nuclear medicine department or at a nuclear pharmacy. The radioactive tracer is injected into the body and is absorbed by the target organ(s) of interest. Once the radionuclide is resident in the organ, the individual is scanned by a gamma scintillation camera and organ function is visualized. The half-lives of most radionuclides used in nuclear medicine are short, and radioactive waste is routinely held for decay-in-storage before disposal as regular trash.

Diagnostic nuclear medicine sources may be located in clinics, hospitals, or mobile units. Typically, due to the weight and complexity of the gamma scintillation camera and support equipment (nuclear pharmacy, film developing with dark room, shielding, and control console), these

Radionuclides Commonly Used in Nuclear Medicine for Diagnostics Procedures*

Name	Half-Life	Emission	Energy (MeV)
Technetium-99m (Tc-99m)	6.02 hours	Gamma	0.140
Gallium-67 (Ga-67)	77.9 hours	Multiple Gamma Rays	0.093, 0.184, 0.296, 0.388
Indium-111 (In-111)	2.81 days	Gamma Rays	0.173, 0.247
Iron-59 (Fe-59)	45.6 days	Beta Particles	1.570, 0.475
		Multiple Gamma Rays	0.143, 0.192, 1.095, 1.292
Iodine-131 (I-131)	8.05 days	Multiple Gamma Rays	0.080, 0.284, 0.364, 0.637, 0.723

* *List does not include all nuclear medicine radionuclides.*

devices are usually located on the ground or basement floor.

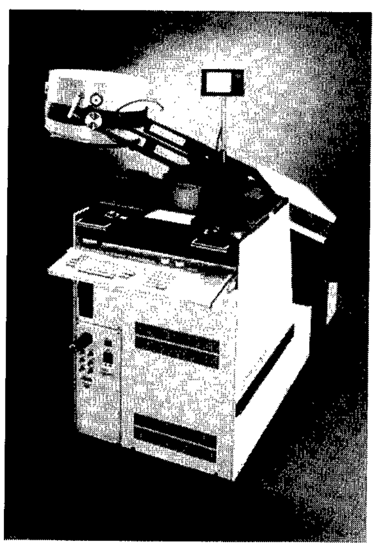
Detection
Nuclear medicine imaging requires gamma photons of sufficient energy to penetrate an individual and interact with a detection device (gamma scintillation camera). Consequently, photon energies are within the range of most field-type radiation detection equipment. Gas-filled ion or Geiger Mueller (GM) chambers (thin or closed window), scintillation detectors, and portal monitors will detect most radionuclides. The survey instrument must be capable of measuring millirem (mrem) or millirad (mrad) per hour. The corresponding Le Système International d'Unités (SI) units are sievert (Sv) and gray (Gy). An example conversion from SI units to traditional units would be 1 μSv = 0.1 mrem or 1 μGy/hr = 0.1 mrad/hr (1 Sv = 100 rem or 1 Gy = 100 rad).

Protection
Most radionuclides used are in liquid form and pose a greater internal than external hazard. If individuals will be handling any object located within a nuclear medicine department, disposable gloves and laboratory coat or apron should be worn. All eating, drinking, smoking, or application of cosmetics is prohibited when in a facility that handles unsealed radioactive materials, since ingestion of these particular types of radionuclides is a major concern.

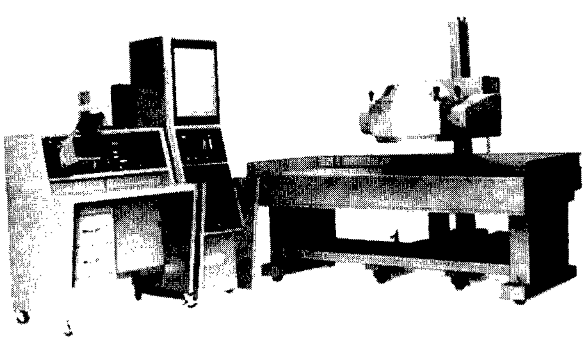
Gamma rays emitted from radionuclides used in nuclear medicine are sufficiently energetic to penetrate an individual. Use the three general principles of radiation protection (time, distance, and shielding) discussed in the front of this handbook.

Hazard Warning and Decontamination Procedures
The potential for a non-lethal whole body exposure exists, particularly if large quantities of radioisotope material are on hand, such as in a storage room or dose preparation room. If the skin or clothing becomes contaminated, take appropriate decontamination measures.

Disposal
The short half-life of most imaging radionuclides will allow decay-in-storage and disposal as regular trash after 10 half-lives. Review the section in the previous chapter on Disposal for guidance.

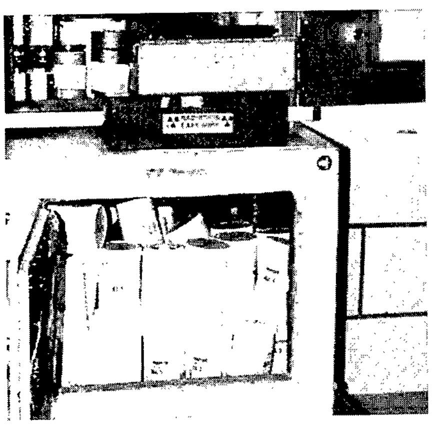


Portable Nuclear Medicine Gamma Scintillation Camera.
(Courtesy of GE Medical Systems)



Nuclear Medicine Gamma Scintillation Camera.
(Courtesy of Searle Radiographics)

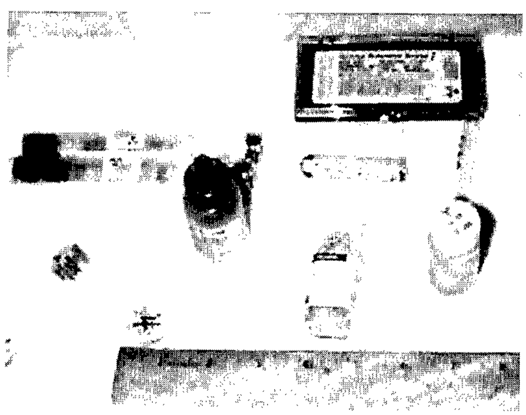
Nuclear Medicine Pharmacies and Associated Equipment



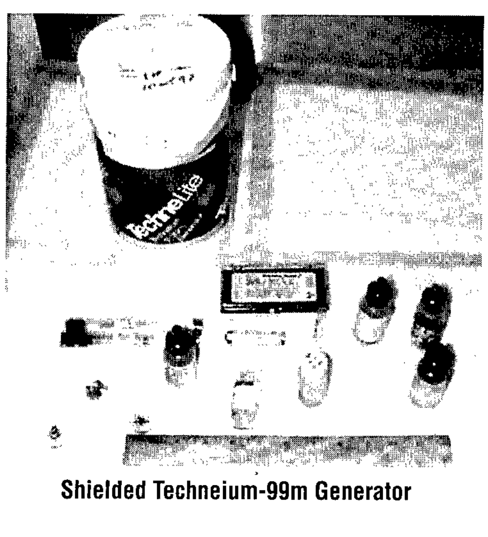
Bulk Decay in Storage and Supplies

Shielded Safe and Syringe Holder

Nuclear Medicine Pharmacies and Associated Equipment (continued)



Small Sources from Nuclear Medicine



Shielded Techneium-99m Generator

(Digital Images Courtesy of Naval Medical Center, Portsmouth, Virginia and Navy Environmental Health Center, Norfolk, Virginia)

Radioactive Sources Commonly Used in Teletherapy

Warning - Source of Potential Fatal Exposure

Background Discussion

Teletherapy, or external beam radiation therapy, is the use of highly collimated (focused) fields of ionizing radiation in the treatment of cancer. A teletherapy beam originates from either a cobalt-60 (Co-60) or cesium-137 (Cs-137) source. Beam therapy devices are always large, heavily shielded (lead and steel), and generally will be clearly marked as containing radioactive material. Teletherapy units generally are located in rooms or vaults at ground or basement level because of their weight and shielding requirements.

A recent technological advancement in radiation therapy is the use of a linear accelerator (LINAC) for the production of high energy x-rays and particles for external beam cancer teletherapy. Although this device does not contain a radioactive source, the LINAC is capable of producing highly penetrating ionizing radiation. Similar to an x-ray machine, it will not produce radiation unless it is energized and operating. LINACs will look very similar to an external beam teletherapy device and will usually be located on a ground floor or basement within a shielded maze and vault.

Radionuclides Commonly Used in External Beam Teletherapy

Name	Half-Life	Emission	Energy (MeV)
Cobalt-60 (Co-60)	5.27 years	Gamma	1.173, 1.332
Cesium-137 (Cs-137)	30 years	Gamma	0.662

Detection

The radiation sources used in teletherapy are retracted to a heavily shielded position inside the teletherapy device when not in use (stored). If in the shielded position, radiation readings will be close to "normal" background levels. If it is believed that a teletherapy unit has been

located, approach the area cautiously with a survey meter operating on its lowest scale. Remember, radiation will not “bend around corners.” Detection equipment should be held or remotely manipulated around corners before entry if it is suspected that a source is in the unshielded position or damaged. **Continuously observe the survey instrument for any sudden significant rise or off scale reading. If this occurs, the source may be unshielded or the shielding may be damaged. Evacuate the area at once!**

Protection

Teletherapy vault walls (30 to 90 centimeters (cm) thick) are composed of concrete with reinforced steel. However, throughout the world, concrete is not poured to the same standards for uniform density, and voids can be incorporated in vault walls as a means to cut cost. If a shielded vault is encountered, do not “assume” that the vault is seamless and of uniform thickness. Radiation "hot spots" may be present.

A teletherapy vault entrance will have several right angle turns (maze) to reduce radiation intensity from within the vault. The door leading into the vault may or may not be lead lined. Accidental entry into a teletherapy vault may be prevented by interlocks between the door and source shield. Cross connecting (purposeful defeat) the electrical interlock is the most common cause of accidental exposures. Electrical interlocks are required in the United States by law but may not be encountered in teletherapy vaults in other countries.

Disposal

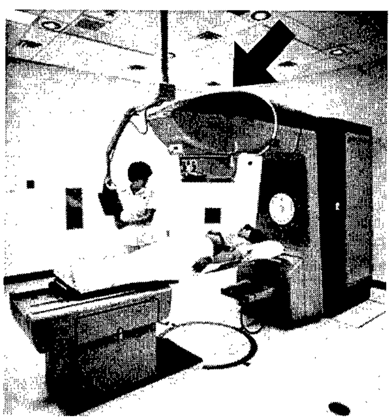
The disposal of a teletherapy unit can be performed only by skilled professionals. Disposal cannot be performed by field personnel. Historically, many of the world’s worst reported radiation accidents have been due to the inappropriate dismantling of a teletherapy device for scrap metal or spare parts.

Cobalt Source Capsule. Teletherapy cobalt-60 source pellets from incapsulated canister.
(Courtesy of Charles C. Thomas, Publisher)

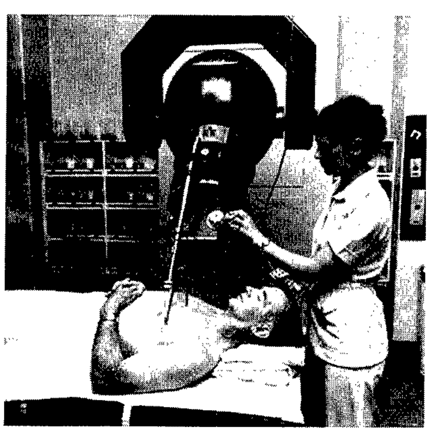
Hazard Warning

A fatal exposure may occur within minutes if the shielded housing is breached and the Co-60 or Cs-137 source is exposed at close range. A whole body irradiation, which *has the potential* of delivering a lethal dose, is possible in a matter of minutes.

Personnel entering a damaged facility that may have been used in the treatment of cancer with teletherapy should enter with a radiation detection device switched on.



Teletherapy Machine in a Cancer Therapy (Oncology) Department. The radiation source is located in the region marked by the arrrow. (Courtesy of Williams and Wilkins)



Cobalt Teletherapy Machine in Cancer Therapy (Oncology) Department. The radiation source is located in the spherical section above the patient. (Courtesy of Charles C. Thomas, Publisher)

Radioactive Sources Commonly Used in Brachytherapy

Background Discussion

Brachytherapy involves the use of encapsulated cobalt-60 (Co-60), cesium-137 (Cs-137), iridium-192 (Ir-192), or radium-226 (Ra-226) sources, surgically implanted into a tumor or inserted into a body orifice to locally irradiate a region for the treatment of cancer. Brachytherapy may be used in a medical treatment facility in lieu of external beam teletherapy because of the reduced equipment cost. Brachytherapy sources are small (1 to 6 cm or even smaller) in length and will be of various shapes. Typically, brachytherapy sources are

- flattened bands, pointed at both ends (0. 5 x 6 cm),
- cylinders, rounded or pointed at one or both ends (0.25 x 3 cm), or
- cylinders, with a wire attached to one end (0.25 x 3 cm).

Radiation Sources Commonly Used in Brachytherapy*

Name	Half-Life	Emission	Energy (MeV)
Cobalt-60 (Co-60)	5.27 years	Gamma	1.173, 1.332
Cesium-137 (Cs-137)	30 years	Gamma	0.662
Iridium-192 (Ir-192)	74.2 days	Multiple Gamma Rays	0.296, 0.308, 0.317, 0.468
Radium-226 (Ra-226)	1620 years	Multiple Gamma Rays	0.180, 0.241, 0.294, 0.350, 0.607, 0.766, 0.933, 1.120, 1.238, 1.379, 1.761, 2.198

* *List does not include all brachytherapy sources.*

Detection

Radioactive sources used in brachytherapy are stored in shielded source containers when not in use. If properly shielded, ambient radiation readings will be near background levels. If it is believed that a brachytherapy source has been located, approach the area cautiously with a survey

meter operating on its lowest scale. Remember, radiation will not "bend around corners." Detection equipment should be held or remotely manipulated around corners before entry if it is suspected that a source is unshielded or damaged. **Continuously observe the survey instrument for any sudden significant rise or off scale reading. If this occurs, the source may be unshielded or the shielding may be damaged. Evacuate the area at once!**

Protection

Radioactive sources used in brachytherapy can cause serious localized injury to extremities if the source is touched. A lethal whole body exposure from a brachytherapy source is not likely, but cannot be completely dismissed. Extreme care must be exercised if entering abandoned or deserted medical treatment facilities that may have performed teletherapy, brachytherapy, or both.

Brachytherapy sources are susceptible to damage because of their size and shape. The source dimensions described above are merely an encapsulation for the source, with the radioactive material distributed inside. Damage to the encapsulation can release the radioactive material into the environment.

Hazard Warning

A potentially serious exposure could occur within minutes to hours if any of these sources are handled. Loose sources must NEVER be handled with bare hands. Irreversible tissue damage will result, with loss of fingers, hands, or arms. There is NO medical treatment for localized radiation damage short of amputation for the control of infection.

Disposal

The disposal of brachytherapy sources must be performed by skilled health physics professionals. Disposal should not be performed by field personnel.

Radioactive Sources Commonly Used in Gamma Radiography *(Warning - Source of Potential Fatal Exposure)*

Background Discussion

Gamma radiography, or industrial radiography, involves the use of encapsulated cesium-137 (Cs-137), cobalt-60 (Co-60), iridium-192 (Ir-192), or possibly radium-226 (Ra-226) sources to validate the integrity of welds in critical piping systems. Major industrial sites, such as oil fields, oil refineries, shipyards, chemical processing plants, and manufacturing plants, usually will employ industrial radiography in some form. Radiography involves the process of threading a wire or cable, tipped with a source, through a hollow tube into a piping system that recently has been welded. New weld sites are wrapped with x-ray film and marked. The guide wire or cable is attached to a highly radioactive source, which is "cranked out" from within its shielding and pushed through the guide tube into the piping system. The source is the approximate size and shape of a 22 caliber cartridge attached to a steel cable.

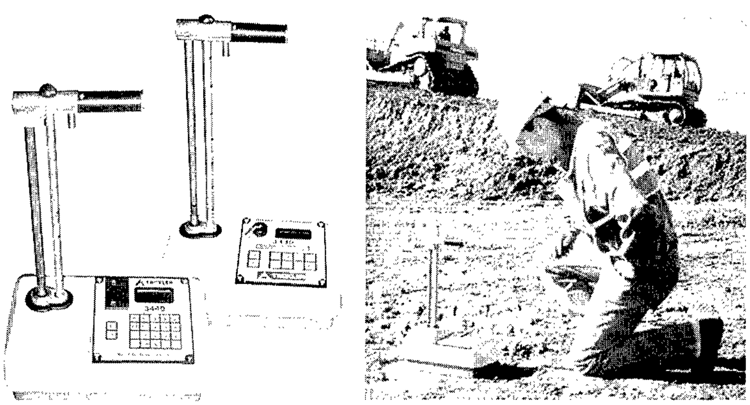
Radiation Sources Commonly Used in Industrial Gamma Radiography

Name	Half-Life	Emission	Energy (MeV)
Cesium-137 (Cs-137)	30 years	Gamma	0.662
Cobalt-60 (Co-60)	5.27 years	Gamma	1.173, 1.332
Iridium-192 (Ir-192)	74.2 days	Multiple Gamma Rays	0.296, 0.308, 0.317, 0.468
Radium-226 (Ra-226)	1620 years	Multiple Gamma Rays	0.180, 0.241, 0.294, 0.350, 0.607, 0.766 0.933, 1.120, 1.238, 1.379, 1.761, 2.198

Moisture-Density Meters

Moisture-density meters are commonly found at construction areas for highways or major buildings, and are used by well drilling companies. These instruments measure the density and moisture content of materials by detecting backscattered gamma photons and neutrons. Moisture-density meters are roughly the size and shape of a shoe box and are equipped with a digital or analog meter mounted on the top. These devices are designed for safety and provide shielding for the sources if they remain within the instrument. No attempt should be made to access the sources directly or handle the instrument if it has been damaged.

Moisture-density meters use a combination of radionuclides to produce neutrons such as americium and beryllium (AmBe) or radium and beryllium (RaBe). Most detectors also possess an internal cesium (Cs-137) source for gamma photons.



Moisture-Density Meters in use at construction sites for the measurement of material density and water content. (Courtesy of Troxler Electronic Laboratories, Inc.)

Detection

Sources used in industrial radiography are highly radioactive, and, if properly shielded, ambient radiation readings usually will be 10 times background levels. If the source has become disconnected from the guide wire and lost at the work site, radiation levels will be extremely high.

Protection

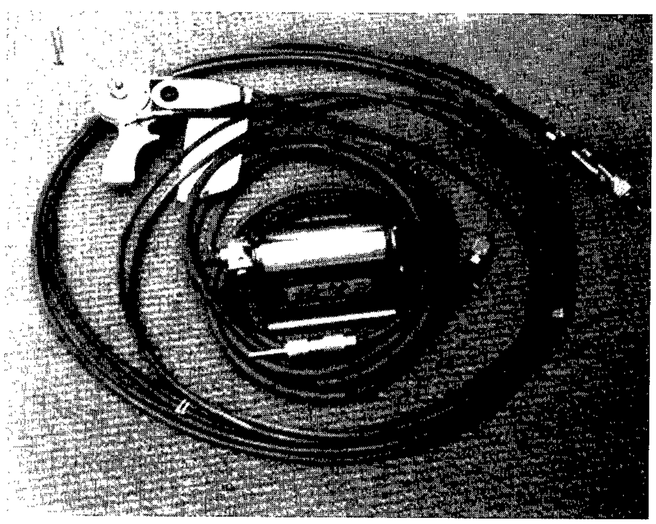
Radioactive sources used in industrial radiography may be stored anywhere on an industrial complex when not in use. The specific activity of these sources is very high, and exposure to the source for only 1 hour could produce a lethal dose. Historically, some of the worst radiation accidents involving loss of life are attributed to careless use and storage of industrial radiography sources. Radioactive sources used in industrial radiography potentially can cause very serious localized injuries. A whole body dose from an industrial radiography source is less likely, but cannot be completely dismissed. Extreme care must be exercised if entering an abandoned industrial site where industrial radiography equipment may be stored or in use.

Disposal

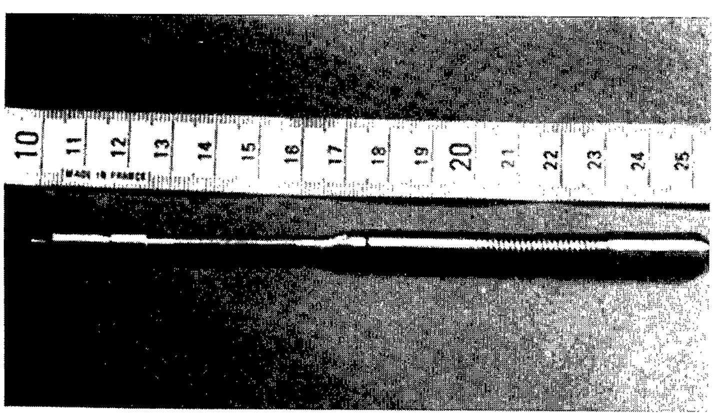
The disposal of industrial radiography sources must be performed by skilled health physics professionals. Disposal should not be performed by field personnel.

Hazard Warning

The specific activity of these sources is very high, and unshielded exposure to these sources at a distance of 30 cm or less may deliver a lethal dose in minutes to hours. Loose sources must NEVER be handled with bare hands. Serious irreversible tissue damage will result, with loss of fingers, hands, or arms. There is NO medical treatment for localized radiation damage short of amputation for the control of infection.



Gamma Radiograpy Crank and Cable Equipment. Radiography source is housed in the center of the coil. (Courtesy of Elsevier North Holland)



Gamma Radiography Source. Located in the end (right). (Courtesy of Elsevier North Holland)

Radioactive Materials in Commodities

Background Discussion
Commercial products (for example, smoke detectors or luminous dials) containing radioactive materials are common in industrialized countries. The presence of a radioactive component or part does not indicate that the commodity is hazardous. Often the radionuclide is fully encapsulated and shielded, and physical tampering is necessary to expose the source. Typically, the quantity of material incorporated into commodities is exempt from control. Activities on the order of microcuries (μCi) or nanocuries (nCi) are encountered, except in the case of old radium-containing equipment that may yield several mR/hr on contact.

Radiation Sources Commonly Used In Commodities

Thorium-232 (Th-232)
Thorium occasionally is added to aircraft control surfaces, leading edges, and gear box components as a strengthening agent. The percent of thorium is 2.5 percent or less. Thorium also is used in welding rods as an additive. Thorium is not considered a radiological hazard unless the material is smelted or undergoes mechanical alteration (by chipping or grinding) and inhaled. Smoke or particulate suspension may become an inhalation hazard to the lung/sinus tissue. Gas camping lantern mantles also contain thorium, and care must be taken to avoid spreading the ash.

Americium-241 (Am-241)
Smoke detectors commonly are equipped with an encapsulated (shielded) source of americium-241 (Am-241) or, rarely, radium-226 (Ra-226). There is no radiological hazard involved with the source as long as the detector is not dismantled and the "source compartment" remains intact. An activity of 10 μCi (residential) to 100 μCi (commercial) is typical in smoke detectors.

Luminous Materials: Radium (Ra-226), Tritium (H-3), Promethium (Pm-147), Krypton (Kr-85)
Luminous phosphor agents are added to instruments, devices, and controls to enhance visibility in the dark. There are three radioactive

materials commonly used that may be incorporated into these devices. Radium-226 (Ra-226) was the most frequently used phosphorescent paint from the 1920s to present. Its use is widely discouraged by the International Atomic Energy Agency (IAEA) because of its radiological toxicity. Frequently, the Ra-226 phosphorescent gauge or dial will leak around the glass face plate or back cover, and will be detectable. Care must be taken not to damage the housing and release any of the loose paint particles from inside the dial or gauge. Tritium (H-3), krypton (Kr-85), and promethium-147 (Pm-147) are commonly used radioactive materials, replacing Ra-226. Tritium (H-3) and krypton (Kr-85) are gases which are pumped into thin tubing (signs) or into gauges. The promethium-147 (Pm-147) is a solid and is painted or imprinted onto dials or gauges.

Detection

Dials or gauges that use Ra-226 may be detected at several meters with an ion chamber or sensitive scintillation detector, yielding an exposure rate of 1 to 5 mR/hr at one-half meter. Promethium is a beta emitter and is detectable as 2 to 3 times background radiation levels.

Protection

Damage to the enclosure integrity will cause H-3 gas to escape into the atmosphere. Stockpiles of H-3 filled signs are not considered a radiological hazard. Promethium will deliver an exposure of 0.1 mrad/hr at 10 cm for a diver's watch, or 0.1 mrad/hr at 1 cm from a pocket watch. Wall clocks or larger signs will deliver a greater dose, approximately 0.2 mrad/hr at 10 cm, because of the volume of material present in these devices.

Disposal or Hazard Warning and Decontamination Procedures

No personnel hazard exists unless a Ra-226 dial is damaged or leaks, and the paint enters the digestive system through ingestion.

Commercial Irradiation of Products

Background Discussion

Irradiation of food and commercial products has become commonplace in many countries, including the United States. Produce and food is irradiated to eliminate harmful microorganisms from commodities such as vegetables, spices, fruits, etc., or to retard spoilage of food. Prolonged exposure is required for the sterilization of medical and surgical supplies. The irradiation process involves passing the food (or material to be sterilized) through a radiation field on a conveyor belt at a set speed to control the exposure time and delivered dose. The food never comes into direct contact with the radiation source.

There are two basic sources for ionizing radiation used in irradiators. The first is the use of a linear accelerator to generate very high energy electrons that bombard a large water-cooled tungsten target, similar to the production of medical x-rays. The second, more commonly encountered, source of radiation is the use of very large fixed radiation sources such as cesium-137 or cobalt-60.

Irradiators used by universities, hospitals, and biomedical research facilities can be any size and source strength. Typically, irradiators used for research and medicine are heavily shielded with fail-safe interlocks preventing accidental or inadvertent exposure. They are designed to irradiate small samples of material capable of fitting into an interior irradiator vault compartment. The door of the irradiator vault is typically mechanically connected to the source, preventing an accidental alignment of the source and open door.

Radionuclides Commonly Used in Commercial Irradiators

Name	Half-Life	Emission	Energy (MeV)
Cobalt-60 (Co-60)	5.27 years	Gamma	1.173, 1.332
Cesium-137 (Cs-137)	30 years	Gamma	0.662

Detection

Sources used in industrial irradiators are extraordinarily radioactive, and, if properly shielded, ambient radiation readings usually will be detectable background levels. If the cobalt-60 or cesium-137 sources have become exposed because of damage to the storage pool and surrounding shielding, radiation levels will be extremely high. Irradiators that employ a linear accelerator (LINAC) cease to produce x-rays when the power is discontinued. A LINAC irradiator will generate detectable radiation adjacent to the facility only during operation.

Protection

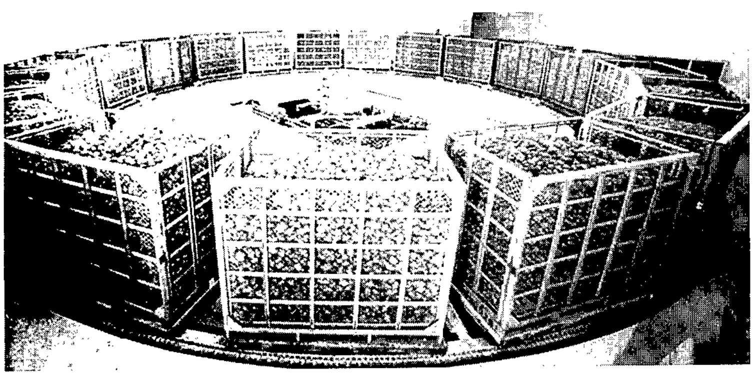
Radioactive sources used in industrial irradiators must be heavily shielded during periods of operation and throughout storage. An irradiator possesses sources capable of producing a fatal exposure within seconds to minutes. As a precaution, electronic and mechanical interlocks are incorporated into the design of the facility to preclude an accidental or inadvertent exposure. However, individuals have been known to defeat the interlocks for various reasons with disastrous and often fatal results. Extreme care must be exercised if entering an abandoned irradiator facility where sources may be in storage, use, or damaged.

Disposal

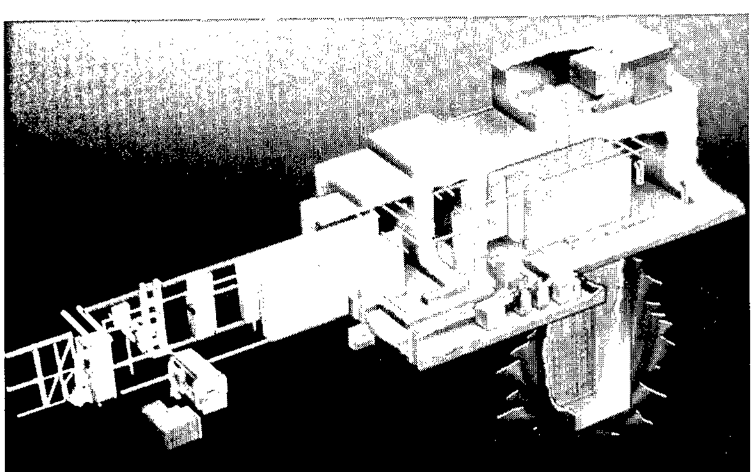
The disposal of irradiator sources must be performed by skilled professionals and must not be attempted by field personnel.

Hazard Warning

The specific activity of these sources is very high, and unshielded exposure to these sources WILL deliver a lethal dose in seconds to minutes. There is NO medical treatment for whole body exposure at doses associated with industrial irradiators.



Commercial Food Irradiator. Produce undergoing irradiation to retard spoilage and eliminate infestation. (Courtesy of the International Atomic Energy Agency)



Commercial Irradiator Facility. Conveyor belt carries material to be irradiated through exposure vault. Large cesium-137 or cobalt-60 sources are located underground in a storage pool and raised as required. (Courtesy of the International Atomic Energy Agency)

Appendix 1. Commonly Used Radionuclides in Medicine, Research, and Industry

Isotope	Symbol	Uses
Americum-241	Am-241	In smoke detectors; to measure levels of toxic lead in dried paint samples; to ensure uniform thickness in rolling processes like steel and paper production; and to help determine where oil wells should be drilled.
Cadmium-109	Cd-109	Used to analyze metal alloys for checking stock, scrap sorting.
Calcium-47	Ca-47	Biomedical research on cellular functions and bone formation.
Californium-252	Cf-252	To inspect airline luggage for hidden explosives; to gauge moisture content of soil; and to measure moisture of materials stored in soils.
Carbon -14	C-14	In research to ensure new drugs are metabolized without harmful by-products. In bioresearch, agriculture, pollution control, and archeology.
Cesium-137	Cs-137	Treats tumors; measures correct dosages of radiopharmaceuticals; to measure and control flow in oil pipelines; to ensure the right fill level for packages of food, drugs and other products.
Chromium-51	Cr-51	Used in research in red blood cell survival studies.
Cobalt-57	Co-57	Used as a tracer to diagnose pernicious anemia.
Cobalt-60	Co-60	To sterilize surgical instruments; to improve safety and reliability of fuel oil burners. In cancer treatment, food irradiation, gauges, radiography.
Copper-67	Cu-67	With monoclonal antibodies, helps bind to and destroy a cancerous tumor.

Appendix 1. Commonly Used Radionuclides in Medicine, Research, and Industry (continued)

Isotope	Symbol	Uses
Curium-244	Cm-244	To analyze excavated mining material; and slurries from drilling.
Gallium-67	Ga-67	Used in medical diagnosis.
Iodine-123	I-123	To diagnose thyroid disorders and others, including brain function.
Iodine-125	I-125	To diagnose thyroid disorders. Also used in biomedical research.
Iodine-129	I-129	To check counters in in-vitro diagnostic testing laboratories.
Iodine-131	I-131	To treat thyroid disorders. (Former President and Mrs. Bush both successfully treated for Graves' disease, a thyroid disease, with iodine-131.)
Iridium-192	Ir-192	To test integrity of welds, boilers, and aircraft parts and in brachytherapy/tumor irradiation.
Iron-55	Fe-55	To analyze electroplating solutions and sulfur in air.
Krypton-85	Kr-85	Indicator lights of appliances, stereos, coffee makers; gauge thickness of plastics/sheet metal/rubber/textiles/paper; measure dust and pollutant levels.
Nickel-63	Ni-63	To detect explosives, and in voltage regulators and current surge protectors, and in electron capture detectors for gas chromatography.
Phosphorus-32/33	P-32, P-33	Used in molecular biology and genetics research.
Plutonium-238	Pu-238	Provided electric power on board more than 20 NASA spacecraft since 1972. (Radioisotope Thermoelectric Generators RTGs)

Appendix 1. Commonly Used Radionuclides in Medicine, Research, and Industry (continued)

Isotope	Symbol	Uses
Polonium-210	Po-210	Reduces static charge in making photographic film and materials.
Promethium-147	Pr-147	Used in electric blanket thermostats; and to gauge the thickness of thin plastics, thin sheet metal, rubber, textile and paper.
Radium-226	Ra-226	Makes lightning rods more effective. Previously used in luminous paint for dials and gauges.
Selenium-75	Se-75	Used in protein studies in life science research.
Sodium-24	Na-24	To locate leaks in industrial pipe lines; and in oil well studies.
Strontium-85	Sr-85	Used to study bone formation and metabolism.
Sulfur-35	S-35	In survey meters by schools, military and emergency management authorities. Also in cigarette manufacturing sensors and medical treatment.
Technetium-99m	Tc-99m	In genetics and molecular biology research. Most widely used radioactive pharmaceutical for diagnostic studies. Different chemical forms used for brain, bone, liver, spleen, and kidney imaging and also blood flow studies.
Thallium-201	Tl-201	Used for nuclear cardiology and tumor detection.
Thallium-204	Tl-204	Measures the dust and pollutant levels on filter paper; and gauges the thickness of plastics, sheet metal, rubber, textiles and paper.
Thoriated Tungsten	Th-232	Used in arc welding rods in construction, aircraft, petrochemical and food processing equipment industries.

Appendix 1. Commonly Used Radionuclides in Medicine, Research, and Industry (continued)

Isotope	Symbol	Uses
Thorium-229	Th-229	Helps fluorescent lights last longer.
Thorium-230	Th-230	Provides coloring and fluorescence in colored glazes and glassware.
Tritium	H-3	Life science and drug metabolism studies to ensure safety of new drugs; self-luminous exit signs; for luminous dials, gauges, and wrist watches; to produce luminous paint, and for geological prospecting and hydrology.
Uranium-234	U-234	Dental crowns and dentures to provide natural color and brightness.
Uranium-235	U-235	Fuel for nuclear power plants; to produce fluorescent glassware, a variety of colored glazes and wall tiles.
Xenon-133	Xe-133	Used in nuclear medicine for lung ventilation and blood flow studies.